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SHAFT SINKING BY ROTARY DRILLING

BY

D. H. PLATT

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SHAFT SINKING BY ROTARY DRILLING[1/]

By D. H. Platt[2/]

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INTRODUCTION

Bauxite, the principal source of aluminum, has been mined from deposits in Saline and Pulaski Counties, Ark., since 1899; war needs have greatly stimulated production.

Many of the ore deposits are basin-shaped and either outcrop or are covered by a shallow-depth overburden at their peripheries; these are mined by stripping and open-pit methods. When stripping becomes economically impracticable, incline shafts or slopes are sunk on the dips of the deposits, and underground mining is done on the retreat, using a room-and-pillar method.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7336."

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Other deposits occur at depth and are covered by Tertiary sands and clays that are usually water-saturated and unconsolidated. Several vertical shafts have been sunk to deposits of this nature, and various means have been devised to retain and stabilize the shafts through the formations encountered during sinking operations. One shaft-sinking method, which in this area has proved to be practicable and satisfactory, employs a large-diameter rotary drill followed by casing and cementing. This paper describes such an operation.

The Reynolds Mining Corp., 1004 Boyle Building, Little Rock, Ark., is mining bauxite through four vertical shafts approximately 2-1/2 miles east of Bauxite, Saline County, Ark., in sec. 12, T. 2 S., R. 14 W., of the fifth principal meridian. The sinking of one of these, the two-compartment No. 4 shaft, Covington mine, Covington-Whitley lease, was contracted by the Layne-Arkansas Co. of Stuttgart, Ark.

ACKNOWLEDGMENTS

R. H. Zeglin, H. T. Middlebrook, and C. Lester Richards are manager, superintendent, and chief engineer, respectively, of the Reynolds Mining Corp., and J. I. Seay and Kenneth Gilbert are president and sales engineer, respectively, of the Layne-Arkansas Co. The courtesies shown and the data, photographs, and cooperation given by all of these officials are hereby gratefully acknowledged. Charles B. Carpenter, Bureau of Mines petroleum engineer, Dallas, Tex., gave his time freely and was of assistance in designating pertinent references.

GENERAL INFORMATION

In the course of preliminary exploration numerous small-diameter holes were drilled; the information thus gained was the determining factor in selecting the site of the No. 4 or Covington shaft. The following log of one drill hole in the immediate vicinity of the shaft shows the drilling time, the unconsolidated nature of the formations, and the depth of the ore horizon; it was used as a guide in preparing shaft sinking estimates.

1-T-124 - Special no. 2 - Covington Elevation of collar - approx. 322 feet, December 9, 1942

Time		Formation	
Feet	Interval	Feet	Description and remarks
0- 10	1 minute	0- 6	Sand.
		6- 7	Gravel.
10- 20	2 minutes	7- 19	Sand.
		19- 23	Red clay.
20- 30	2 minutes	23- 27	Brown clay.
30- 40	1.5 minutes	27- 48	Brown clay with sand seams.
40- 50	2 minutes		
50- 60	4.5 minutes	48- 73	Hard brown clay.
60- 70	5 minutes		
70- 80	3 minutes	73- 78	Brown clay with soft sand seams, especially at 73-74 and 77-77.5.

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1-T-124 - Special no. 2 - Covington Elevation of collar - apprcx. 322 feet, December 9, 1942 (Cont'd)

Time		Formation	
Feet	Interval	Feet	Description and Remarks
80- 90	5 minutes	78- 86	Hard brown clay (80-83 - 2 minutes drilling.)
90-100	1.5 minutes	86- 96	Sandy brown clay
100-110	30 seconds	96-155	Sand, probably some brown clay.
110-120	40 seconds		
120-130	30 seconds		
130-140	30 seconds		
140-150	50 seconds		
150-160	2 minutes	155-158	Clay seam.
		158-163	Sand.
160-170	6 minutes	163-174	Blue gray clay.
170-180	3 minutes	174-176	Sand.
180-190	2 minutes	176-185	Gray sandy clay.
		185-191	Sand.
190-200	6 minutes	191-196	Lignite.
		196-200	Sandy clay (fast drilling).
200-210	7 minutes	200-216	Lignite.
210-220	5 minutes	216-217	Clay seams.
		217-218	Lignite.
220-230	10 minutes	218-224	Clay.
		224-224.5	Rock.
		225-226	Hard bauxite
		226-230	Firm bauxite (4 ft. drilled in 3 minutes).
230-240	9 minutes	230-258	Bauxite.
240-250	9 minutes	245-250	(Noticeable firmer).
250-260	5 minutes		
260-270	8 minutes	258-265	Soft red clay.
		265-279	Red and gray clay.
270-280	7 minutes		
		273	Becomes soft.
		279	Altered syenite.
280-290	4 minutes		
		285-328	Very soft, rotten syenite going into dark blue-gray syenitic sand.
		at 285	Bit dropped as if it were in quicksand.
290-300	45 seconds		
		297-300	Bit dropped in less than 5 seconds.
300-310	20 seconds		Extremely soft sand.
310-320	25 seconds		(Including stopping rotary motion of bit.)
		315-318	Bit dropped without rotary motion.
320-330	3 minutes		
		at 323	Bit chattered - 30 seconds to drill 320-323.
		326-328	Fast drilling.
		328-330	Noticeably firmer material.
330-340	10 minutes	328-340	Gray clay - looks like altered syenitic clay.

Drill cuttings below a depth of 300 feet were washed up with about 10-foot lag. The cuttings correlated with changes in speed of drilling. Samples were collected at 340 feet until nearly all cuttings were gone.

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Other rotary drill, shaft-sinking contracts completed in this mining district by the Layne-Arkansas Co. served as guides in planning the work.

The plans specified the completion of two vertical shafts, each 6 feet 2 inches in diameter in the clear, cased with 1/2-inch steel plate, with an outer seal of cement at least 4-1/2 inches in thickness and sunk on 16.18-foot centers from surface into solid bauxite. The sea-level elevation of the collars of the drill holes was approximately 322 feet, and drilling was to terminate at a depth of 235 feet.

CONVENTIONAL ROTARY-DRILLING METHODS

Since shaft sinking by means of oil-well rotary-drilling equipment is a radical departure from the conventional methods familiar to mining people, a brief summary of a few of the fundamentals is desirable for a more comprehensive understanding of operating problems.

The derricks used are designed from a general form that has developed with oil-field drilling.

The draw works, as described by Uren,3/ serves as a power distribution system center for all power-driven parts of the rig, except the pumps. It consists of two principal parts (1) the hoisting drum with its shaft, supporting boxes, sprockets, clutches, and brakes, and (2) the drive shaft with its supports, several sprockets and clutches, and two "catheads."

The rotary table, which rotates the drill pipe, is operated by either chain or shaft drive from the draw works. It is a heavy steel casting approximately 4 feet in diameter, with a smooth, flat top and a beveled gearing on the lower side. It rotates in a horizontal plane on bearings in a stationary and adequately secured metal base. An opening through the center provides for passage of the drill stem.

In order that the rotary table may have a positive grip on the drill stem, the first 28 to 45 feet below the swivel consists of a specially designed "grief stem" or "kelly joint" of angular form to fit a similarly shaped opening in the rotary table. A cylindrical hole through the kelly joint permits passage of the drilling fluid, and a pipe-thread joint at each end, with suitable collars, provides the means of connecting it with the cylindrical drill pipe and the rotary swivel.

The rotary swivel provides the means of suspending the rotating drill pipe. Drilling fluid is pumped through the rotary swivel into the rotating drill pipe. The rotary swivel is designed with bearings of a diameter capable of supporting the maximum required rotating load with an adequate factor of safety. A complete swivel for a 6-inch drill pipe will weigh approximately 1 ton, and some are designed for a safe working load of 150 tons.

3/ Uren, Lester Charles, Petroleum Production Engineering: McGraw-Hill book Co., New York, 1934, pp. 192 and following.

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The hoisting block serves the double function of handling drill pipe and running casing into the hole. It may contain three to six sheaves, depending upon the service required. A large hook, usually supported on a heavy spring and provided with a safety latch, is suspended well below the center of gravity of the hoisting block; it engages the bail of the rotary swivel, the casing, or the drill-pipe elevators. Heavy-duty blocks may weigh as much as 3 tons and have rated safe working loads of 250 tons. The crown blocks usually are equipped with four or five sheaves mounted side by side on a single horizontal shaft at the top of the derrick.

The drill pipe connecting the drilling bit with the rotary swivel consists of sections of heavy steel pipe. Drill-stem couplings are of special design with recessed threads of extra strength.

Cables composed of 6 strands of 19 or more wires around a hemp core are ordinarily used. One end is always attached to the drum of the draw works and the other, as a dead line, is fastened to the hoisting block or to one of the derrick sills.

Concerning mud pumps, Brantley[4/] states that the size of the pumps to be used on a given operation offers no difficulty. The entire problem lies in determining the proper volume of mud-laden fluid that must be delivered by the pump at the maximum pressure to be encountered. Pumps used in oil well drilling are usually steam-driven, duplex, double-acting types. Centrifugal pumps were used in the Reynolds No. 4 shaft-sinking operation and are described hereinafter.

The mud pumps and the gooseneck of the rotary swivel are usually connected by a heavy-armored, rubber, or canvas hose strung enough to withstand high pressures.

Carpenter[5/] states that drilling by the rotary method consists of rotating a drill bit attached to the lower end of a string of drill pipe. Drilling fluid (mud-laden fluid) is circulated by means of slush pumps downward through the inside of the drill stem and upward through the annular space between the drill stem and the walls of the hole until it reaches the surface and is discharged into the slush pits (mud pits).

Drilling fluids usually are made by mixing natural clays with water, the weight of the mixture depending on the quantity of clay used. The chief functions of a drilling fluid are:

1. To remove cuttings from the hole.

2. To hold solids in suspension when drilling is stopped.

3. To provide a mud sheath on the walls of the hole and thereby retard infiltration of drilling water, which causes caving and sloughing.

4/ Brantley, J. E., Rotary Drilling Handbook: Russel Palmer, 1938.
5/ Carpenter, Charles B., Some Causes of Blow-outs During Drilling and Means of Prevention with Special Reference to the Gulf Coast Region: Bureau of Mines Inf. Circ. 6938, 1937, pp 4-6, 9, 14.

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4. To seal off minor oil, gas and water-bearing formations.

5. To suppress formation pressures by the hydrostatic head of the fluid column.

6. To lubricate the bit and the drill pipe.

7. To cool the bit.

The suppression of formation pressures is one of the most important functions of a drilling fluid, and its weight is carefully controlled.

Water weighs 8.33 pounds per gallon, and a column of water 1 foot high exerts a pressure of 0.4335 pound per square inch at its base. A drilling fluid weighing 10 pounds per gallon (specific gravity, 1.2) exerts a pressure of 0.52 pound per square inch per foot of height and generally will control all normal formation pressures with a margin of safety.

Drilling fluid may become mixed with water, and dilution may reduce weight enough to render it ineffective. Free circulation of drilling fluid in the wall is essential for effective removal of cuttings from the bottom of the hole and lubrication of the bit and pipe.

When all is ready for drilling, a bit is securely screwed to a drill collar and the latter is screwed to the kelly joint. The rotary swivel, suspended from the hoisting block, is connected to the upper end of the kelly joint, and the assembly is lowered through the rotary table to the desired position. Driving bushings are then inserted in the rotary table, a mud pump is started, and the rotary-table clutch is engaged. Cutting begins as the stem rotates. As the hole is deepened, joints of drill pipe are added to the stem, or string of drill pipe, at intervals of 20 to 30 feet. To accomplish this, the pump is stopped, the table clutch is disengaged, driving bushings are removed, and the stem is raised until the lower end of the kelly joint emerges above the rotary table. The drill-pipe slips are placed about the pipe in the table opening, and the stem is lowered until the slips take hold. The table is locked, the kelly joint is unscrewed from the drill collar, and the swivel and kelly joint are hoisted until they clear the lower portion of the joint. The swivel and kelly joint are placed in a "rat hole" (an excavation made under the derrick floor) when not in use. The hook is disengaged from the swivel bail, and another joint of drill pipe is raised and screwed into the drill collar of the top joint of the string of drill pipe. The drill pipe is lowered into the hole until the new joint is about 2 feet above the table, slips are placed about it, and when it is secured the kelly joint and swivel are again attached. The lengthened stem is lowered to drilling position, and drilling is resumed The cycle of operations is repeated until the desired depth is attained.

Casing is necessary to prevent the walls of drill holes from caving and to exclude water. The steel casing must be strong enough to resist

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collapsing pressures originating in the hydrostatic head and to prevent pulling apart under its own weight. Casing diameters are selected that will permit lowering it into the hole, cementing operations and, if necessary, subsequent movement of the drill stem. The casing operation consists of adding individual sections of casing to a reinforcing shoe of steel. Sections are joined either by the use of collars or by welding, and subsequently the casing string is lowered into the mud-filled hole by gravity. Special types of elevators, hooks, blocks, tongs, and bushings are used to handle the casing.

Casing may fail to meet its requirements in a number of ways. It may fail by tension under its own dead, unsupported weight, it may collapse because of pressure due to the hydrostatic head, or it may fail under lateral pressure due to bending stress where caving or shifting formations form cavities of considerable size while the casing is supported against the walls above and below. Numerous other conditions or combinations of conditions may cause casing failure; it should be designed to withstand them. Formulas for determining safe working stresses in casing are given by Uren.6/

Methods employed to cement large-diameter shaft casing differ from those used in cementing oil-well casing and are hereinafter described in the sequence of this operation.

PRELIMINARY WORK

When mining operations were undertaken by the Reynolds Mining Corp. in Saline County, Ark., it was necessary to divert Hurricane Creek from its flowing, meandering course across the flat wooded terrain. This was accomplished by excavating a new channel and constructing a 5,900-foot protecting earthen dike with maximum and minimum dimensions as follows: Width of base, 100 feet and 40 feet; height, 12 feet and 6 feet; and width of top, 25 feet and 8 feet. A considerable portion of the channel and dike was constructed to afford desired protection to the No. 4 shaft area.

All phases of the shaft-sinking operation were conducted by the contractor. Preliminary work was started in December 1942 and consisted of clearing and establishing a camp site; erecting a bunkhouse, boarding house, warehouse, and shop; moving tools and equipment onto location; erecting the derrick; constructing mud pits; and setting machinery.

The collar area was leveled; wooden sills, 18 by 18 inches and 24 feet in length, were placed directly upon the ground, and upon these a wooden derrick 64 feet in height was built. Cellar excavations are not made for this type of drilling operation. To obtain the desired drilling fluid capacity, three mud pits, each 25 by 75 feet in area and 4 to 10 feet in depth, were prepared.

6/ Uren, Lester Charles, Work cited in footnote 3, pp. 301-309.

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DRILLING EQUIPMENT

A general view of the derrick and drilling rig is shown in figure 1.

The equipment consisted of the following units:

1. One heavy-duty draw works, assembled by the Layne-Arkansas Co. and powered by one 75-horsepower, 440-volt, 60-cycle, 3-phase, alternating-current motor.

2. One 24-inch rotary table.

3. A 10-inch drill pipe in 20-foot lengths.

4. A swivel.

5. Heavy-duty blocks assembled by the contractor.

6. The principal mud pump (circulating pump), a 2,500-g.p.m., Layne & Bowler, two-stage, vertical centrifugal with 24-inch impellers set 10 feet below the motor and powered by one 75-horsepower, 440-volt, 60-cycle, 3-phase, alternating-current motor. (See fig. 2.)

7. Two 500-g.p.m., auxiliary, horizontal, centrifugal mud pumps, each powered by 60-horsepower gasoline motors.

8. Five 250-g.p.m., horizontal, centrifugal cementing pumps, four of which were powered by individual 30-horsepower gasoline engines and one of which was powered by a Ford V-8 gasoline engine.

9. An auxiliary rigging winch mounted on a truck and powered by a separate 25-horsepower engine.

A four-edged cutting bit, 24 inches in diameter, was used in drilling the pilot holes. A large bit, 84 inches in diameter and 20 feet long, weighing approximately 7,000 pounds and provided with "Stellite"-coated cutting edges, was used for the reaming operations; at its lower end and integral with it was a cutting bit of the same specifications as that used for drilling the pilot holes. The large reaming bit was developed by the Layne-Arkansas Co. and was designed to follow the course of the pilot hole while reaming. Figure 3 shows side and end views of the reaming bit. Since the design of this tool was not patented, details concerning it necessarily were restricted, and general information only can be given.

DRILLING, REAMING, CASING AND CEMENTING OPERATIONS

At the Reynolds Mining Corp. No. 4 shaft local gumbo clay, of known quality, was thoroughly mixed with water to the desired consistency to form a satisfactory drilling fluid. Drilling of the 24-inch-diameter pilot hole was begun on February 1, 1943. The unclamped drill pipe in the first section of the hole was plumbed with a plumb bob to effect

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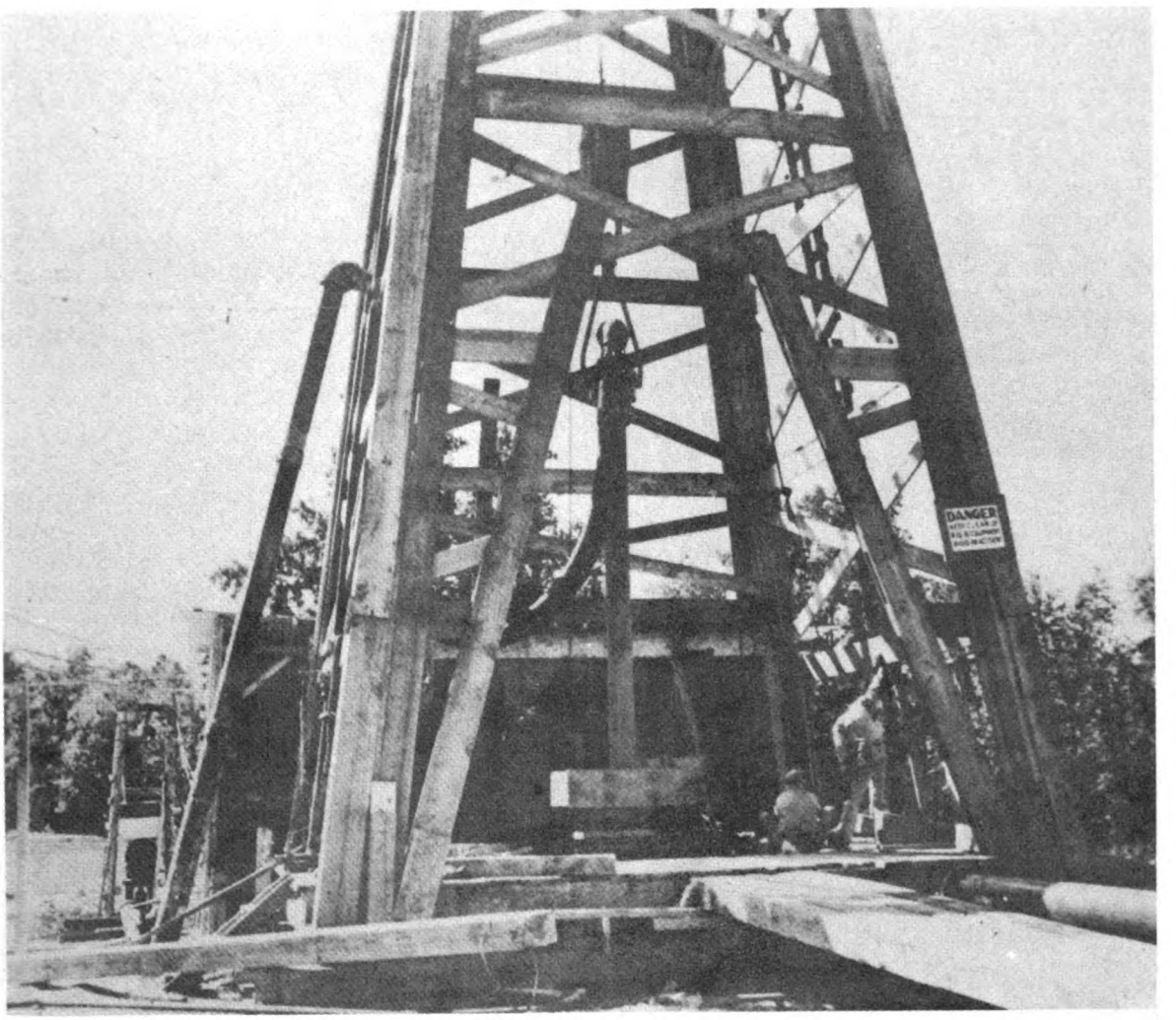

FIGURE 1.- Mud pump, swivel, Kelly joint, and rotary table.

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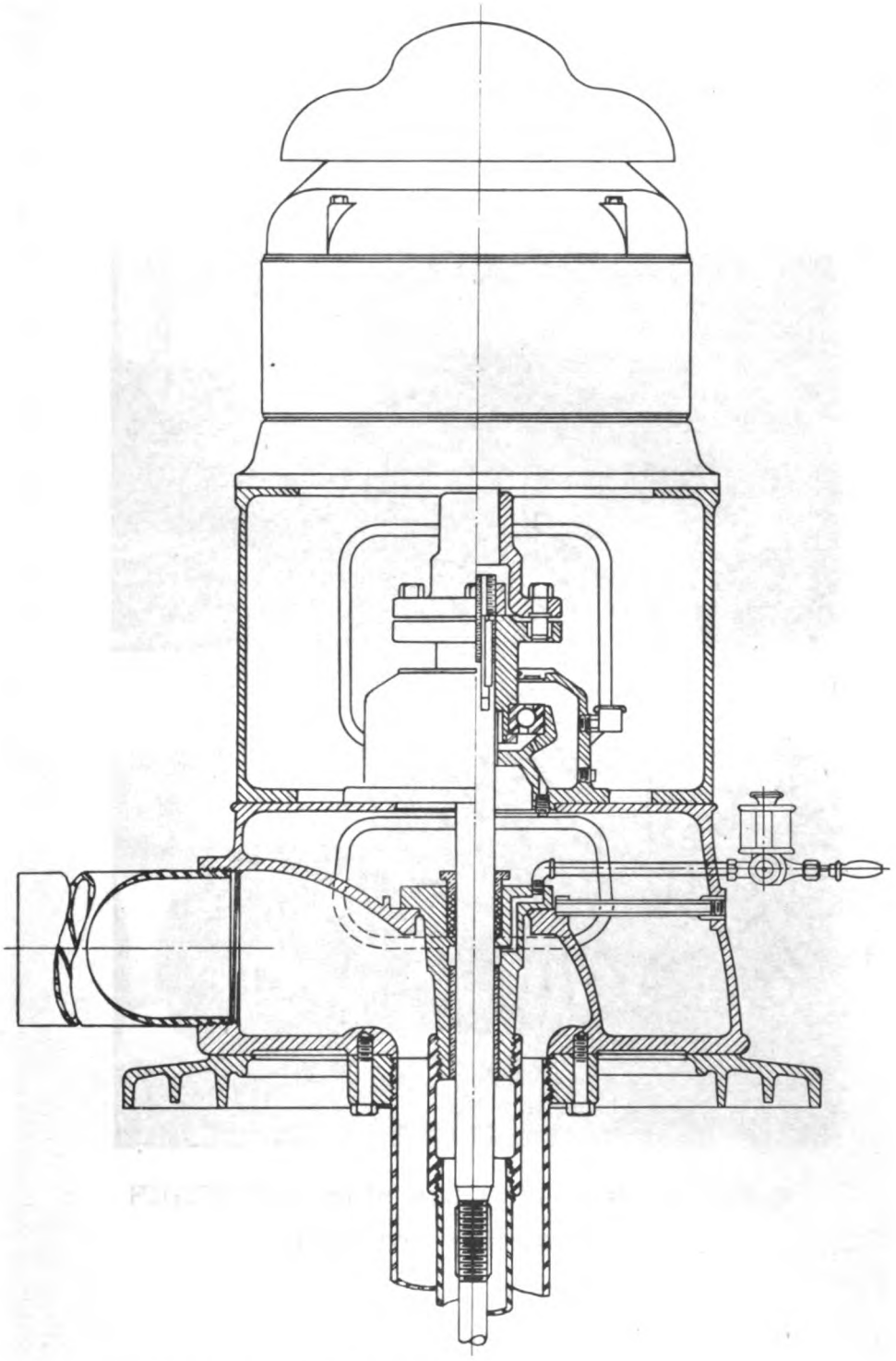

FIGURE 2.- Vertical centrifugal mud pump.

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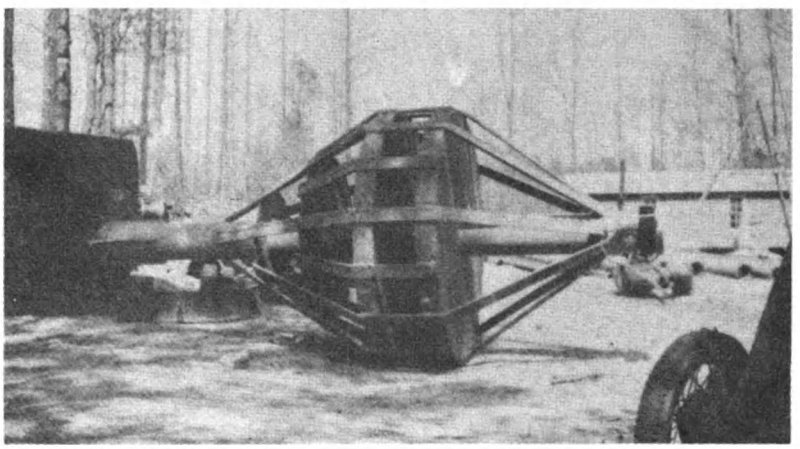

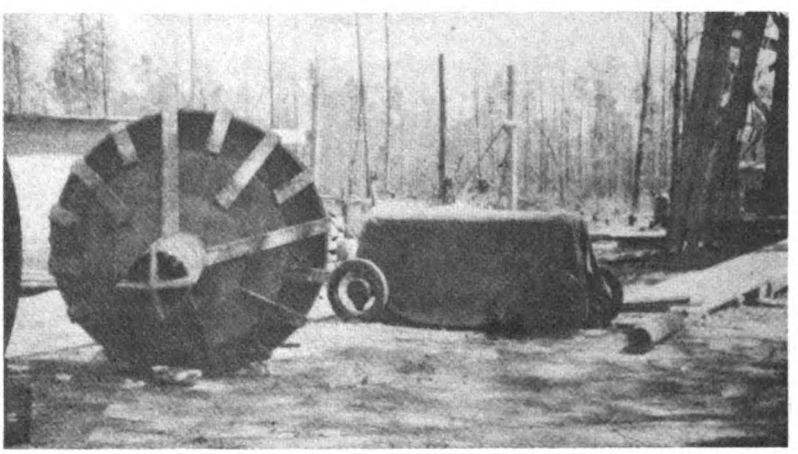

FIGURE 3.- Side and end views of large-diameter reaming bit.

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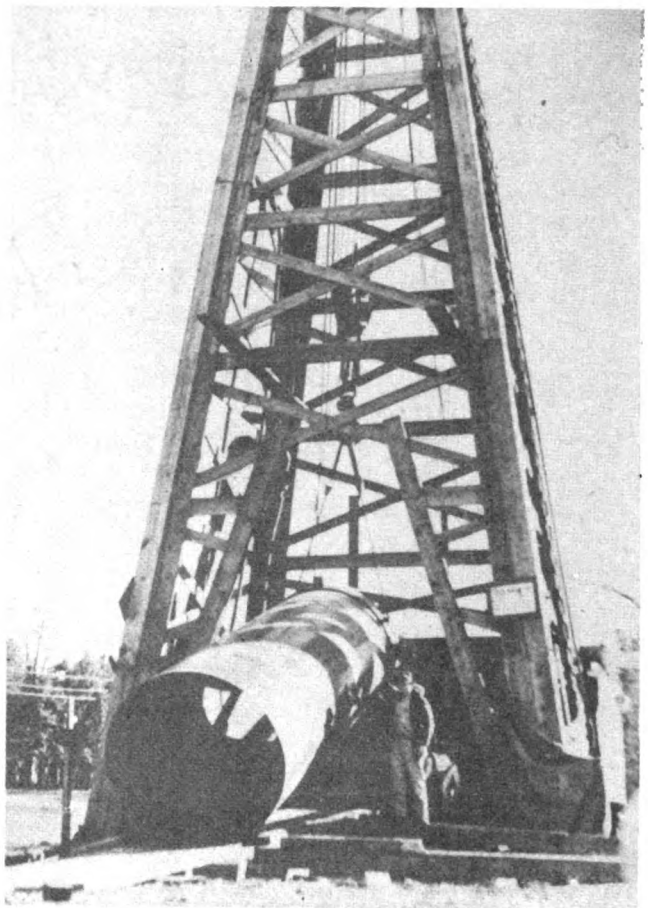

FIGURE 4.- Moving shaft casing into derrick.

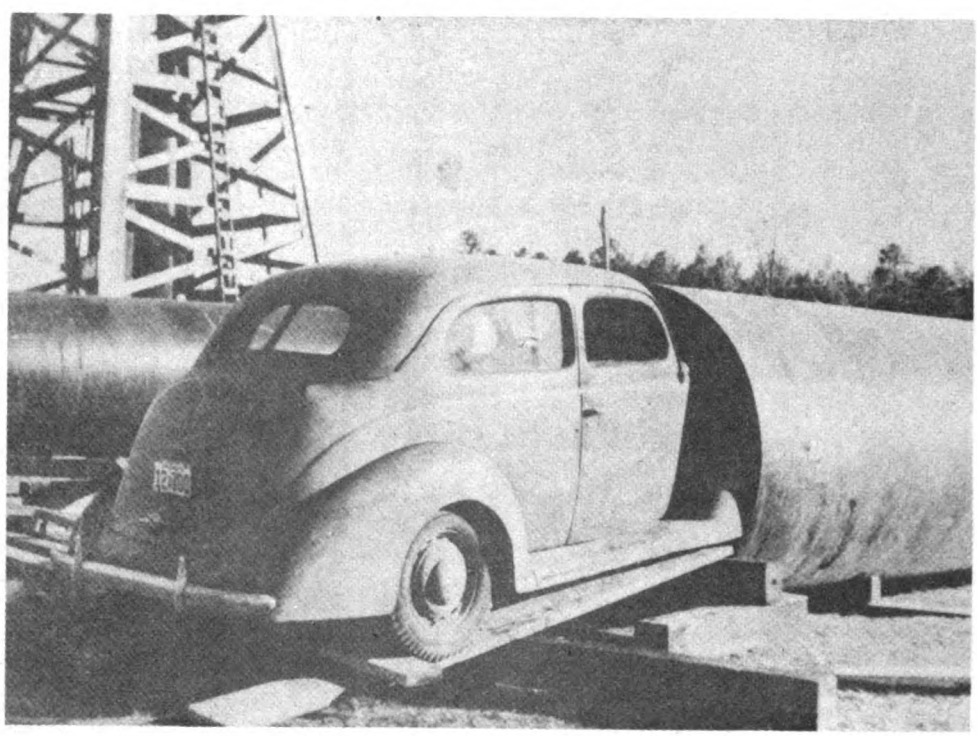

FIGURE 5.- Section of shaft casing and automobile.

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vertical drilling. Four days later this drill hole was completed to a depth of approximately 235 feet. The drill pipe and 24-inch bit were pulled from the mud-filled hole, and the rotary table was removed to permit lowering of the 84-inch-diameter reaming bit. The reaming bit was attached to the drill pipe and centered in the pilot hole. One reaming operation only was necessary. Reaming was begun on February 6. The first 100 feet of the pilot hole was reamed to a diameter of 84 inches in approximately 9 days, and the remainder of the hole (from 100 feet to 228 feet) was reamed in approximately 28 days. Slower progress was made in reaming the last 128 feet because the volume of the drilling fluid had to be increased as the hole was deepened, and it was necessary to spend more time in mixing and maintaining the drilling fluid at the desired consistency. Drilling and reaming were not impeded by equipment failures.

The drilling and reaming tools were removed from the hole after it had been enlarged to a diameter of 84 inches from surfact to 228 feet, and preparations to place the 75-inch-outside-diameter casing were begun immediately. The casing was shop-fabricated from shaped, 1/2-inch, steel plates welded into circular sections 75 inches in diameter and 21 feet in length. One-half-inch by 8-inch steel bands or collars were arc-welded to the outside of one end of each section; 4 inches of each collar extended beyond the end of each casing length. These 21-foot sections were delivered to the contractor at the project site. (See fig. 4)

The 21-foot sections were raised into the derrick by means of specially designed casing elevators (clamps designed to grip the casing securely at one end so that it may be raised or lowered by the draw works and blocks). (Fig. 5.) The first length was centered over the mud-filled shaft and lowered into it by gravity; the use of a casing shoe was not necessary. The casing with welded collars weighs approximately 400 pounds per linear foot.

The lowering operation was controlled by the draw works. Additional casing lengths were added by securing the lowered section or sections at the shaft collar by means of a specially designed casing spider and slips. The casing elevators were then removed from the lowered casing and attached to a new 21-foot section of casing, which was pulled into the derrick, raised, then lowered into the open collar at the upper end of the secured portion; the new section was joined to the lower section or sections while in an upright, vertical position by arc-welding. The lengthened casing string was then raised enough to release the slips, and the lowering operations were repeated until 225 feet of casing had been placed. At this depth the casing was below the top of hard, solid bauxite.

When all of the casing had been lowered, it was secured in the casing clamps, and a 1/2-inch steel cap, with a 4-inch circular hole in the center, was welded over its top. A string of 4-inch-outside-diameter pipe was then lowered to a point 1 foot below the bottom of the casing. The pipe string was welded to the casing cap to effect a perfect seal, and necessary connections were made between the 4-inch pipe string and the mud and the cementing pumps.

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When cement is to be pumped into the annular ring between the outside of the casing and the wall of the hole, circulation must first be effected from the bottom of the casing to the surface by pumping low-density drilling fluid under pressure through the annular ring to dispel all coarse detrital material.

A sack of cement weighing 94 pounds is estimated to have an absolute volume of 0.484 cubic foot. This is the volume of the material minus that of the pore space occluded within it. When mixed with water the volume of the mixture will depend upon the percentage of water relative to the weight of the cement; for example, a 50-percent slurry contains 50 pounds of water for each 100 pounds of dry cement. A mixture having a water-cement ratio by weight of approximately 42 percent (4.75 gallons per sack) is about the average of mixtures used in oil-well cementing operations, and final pump pressures range from 500 to 800 pounds per square inch.

A convenient formula developed by Scott7/ for computing the theoretical quantity of cement necessary to form a neat cement plug about a column of casing is:

$$Q = \frac{F \times (d_1^2 - d^2) \times 0.005454}{V}$$

In this formula Q is the number of sacks of cement required; F is the number of linear feet to be filled in the annular space outside of the casing; d_1 is the diameter of the hole, in inches; d is the outside diameter of the casing in inches; and V is the volume, in cubic feet, occupied by a sack (94 pounds) of cement at a specific water:cement ratio.

In this shaft-sinking operation a water:cement ratio of 1 gallon of water : 15 pounds of cement was selected which, when computed, gives 6.266 gallons per sack of cement, 55.2 percent by weight, 1.36 cubic feet for the volume of each sack based on experimental tests, and 1,313 cubic feet for the theoretical volume of each sack. Upon the foregoing basis the necessary quantity of cement was computed and the cement slurry prepared. The drilling fluid was circulated through the 4-inch pipe line from the bottom of the casing to the surface through the annular ring between the outside of the casing and the walls of the hole to dispel detrital material. The cement slurry was conveyed under pressure through the 4-inch line to the bottom of the shaft. The drilling fluid in the 4-inch line was discharged ahead of the slurry which, when it reached the bottom of the shaft, formed a conical plug. As the plug built up to the vicinity of the bottom of the casing, the slurry ascended through the annular ring discharging the drilling fluid ahead of it. The volume of the drilling fluid discharged was recorded as a further check on the quantity of slurry necessary to make a total seal. In theory, the ascending slurry occupies the entire annular ring and is forced upward at all points in it at a uniform rate. The pressures maintained while introducing the cement slurry during this operation were not given.

The speed with which a cementing operation is completed is important since all cement should be in place before it takes its initial set. In

7/ Scott, B. H., Difficult Conditions Met by Modern Cementing Systems: Oil Field Engineering, Oct. 1928, pp. 23-31.

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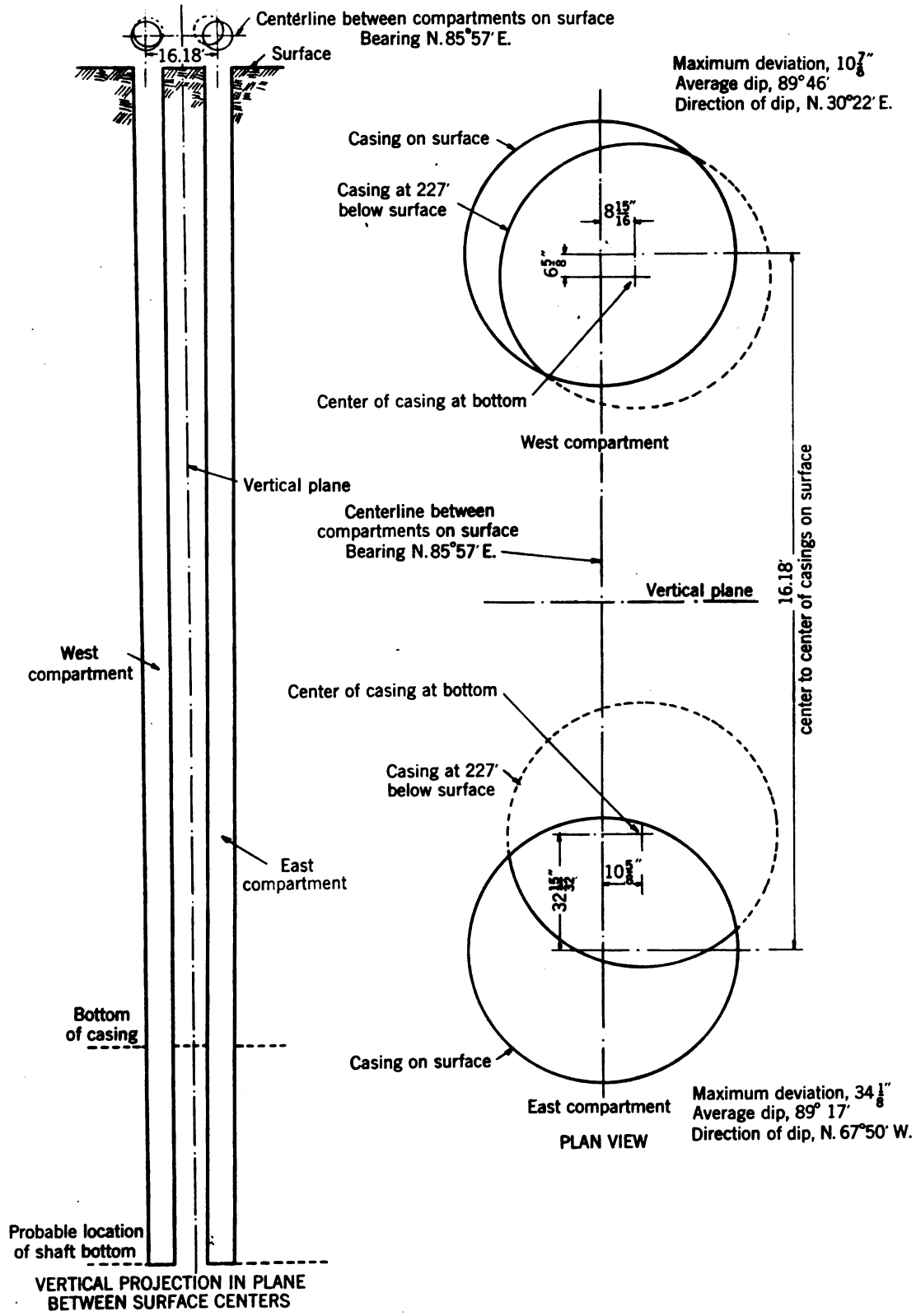

FIGURE 6.- Plan and vertical projection of shaft, showing compartment convergence.

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completing this operation the slurry from 2,100 sacks of cement was pumped into the shaft in 1 hour and 45 minutes.

Four days were allowed for the cement to set. At the expiration of that period the welded cap was cut from the top of the casing, the 4-inch pipe line was removed, and the drilling fluid was bailed from the shaft. The first unit of the contract was completed on April 1, 1943. The casing was sounded throughout its inner periphery and length to ascertain the effectiveness of the cement seal. Neither voids nor density changes were evidenced, and these tests, with the fact that there was no appreciable percolation of water from the lower end of the seal, indicated that desired conditions had been achieved.

The same methods and cycles of operation were employed in sinking the second unit or compartment of the shaft. The preliminary work was completed before May 1, 1943, and drilling of the pilot hole was begun that date. Casing, cementing, and cleaning were successively done, and the contract was completed on July 1, 1943.

Before the shaft could be placed in operation, it was necessary for the company to erect surface structures, install machinery, and equip the shaft with air lines, power circuits, a ladder, and guides for skips. In addition, both shaft compartments were sunk to the floor of the working level 246.2 feet below the collar, and subsequently both were sunk an additional 26 feet to permit the installation of skip pockets.

Before skip guides were installed, both compartments were plumbed to ascertain the extent to which each had deviated from vertical at all points between the collars and the bottoms of the casings. The center of the bottom of the west compartment was found to be 8-15/16 inches north and 6-5/8 inches east of the center on surface, and the center of the bottom of the east compartment was found to be 10-5/8 inches north and 32-15/32 inches west of the center on surface. The compartments converged and inclined to the north from top to bottom. (See fig. 6.)

To establish proper alignment for skip pocket installations, to minimize maintenance costs and the operating strains upon the hoist and head frame, it was deemed advisable to install the skip guides in each compartment on incline planes with strikes parallel to the collar center line and dipping and raking in a direction determined by the relative positions of the center of each compartment on the surface and at the bottoms of the casings. To establish the correct alignment, the bearing between the centres of the compartments on surface was determined by actual survey, and the center line was marked upon the inner peripheries of the casings at the collars. The identical center-line bearing was then established underground by a shaft-plumbing operation, and this bearing was subsequently established through the center of each compartment at the bottoms of the casings and marked on their inner peripheries.

A computed bearing, at right angles to the bearing between the center line of the compartments, was established and marked upon the inner peripheries of the collar and bottom of each casing. Wires were stretched between

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the corresponding northerly and southerly top and bottom points and secured at the top and bottom. The plane between these wires was on the rake.

Forty-pound T-rails were used as skip guides. These had to be supported and stabilized in the circular cross-sectioned shaft compartments to provide a space of 4 feet, 5-1/2 inches, between the inner or wearing surfaces of the rail guides. To accomplish the first two objectives and assist in aligning the guides, 3- by 3-inch by 3/8-inch steel angle form spreaders were bevel-cut to a length calculated to fit the arc of the casing circumference and maintain the desired space between any pair of parallel horizontally placed spreaders, the ends of which were in contact with the casing.

The T-rail guides were connected at the shaft collar by means of bolted fish plates, and the spreaders were bolted to the rail flanges at 6-foot intervals. Each guide was lowered as it was assembled, and when it reached the depth of the bottom of the casing it was securely fastened to the head frame, but each could be moved circumferentially as the attached spreaders permitted.

To facilitate the installation and alignment of the skip guides, a wooden cage with open sides was constructed which allowed ready access to the compartment casing. It provided adequate standing and head room and was light enough for maneuverability. Two guide shoes on each side of the cage were spaced approximately 6 feet vertically, and each shoe was 1 foot 6 inches long and of a width and depth that would accommodate the ball and web of 40-pound T-rails. Oak wear strips 1 inch by 2 inches and 18 inches long were bolted to the bottom of the "U" section of each guide shoe. The cage was designed to engage the assembled guides in the guide shoes and, at any vertical location, spread the guides to the spacing required. When the guides were forced into these positions the ends of the guide spreaders were in contact with the casing but the guides were not necessarily in alignment.

It was important to install the guides on the inclined planes of the compartment's center line. To aid in accomplishing this at any desired point, light steel rods were bolted to the floor of the cage perpendicular to a line between the centers of the guide shoes on opposite sides of the cage. These rods extended beyond the edges of the floor of the cage to points approximately 1 inch from the compartment casing.

The rods served as pointers, for by rotating the cage until their ends coincided with the wires which had been strung on the plane of rake in each compartment, the guide assembly with the guides engaged by the guide shoes occupied the desired positions.

While the guide assembly was held in position, the end of each spreader, within the working range of the cage, was securely welded to the compartment casing. The cage was successively lowered and stopped opposite every pair of spreaders long enough to accomplish the aligning and welding operations.

A portable acetylene welding outfit was carried on the floor of the cage, and a welder and one helper, using the method described, installed the guide assemblies in both compartments of the shaft in seven 8-hour working days.

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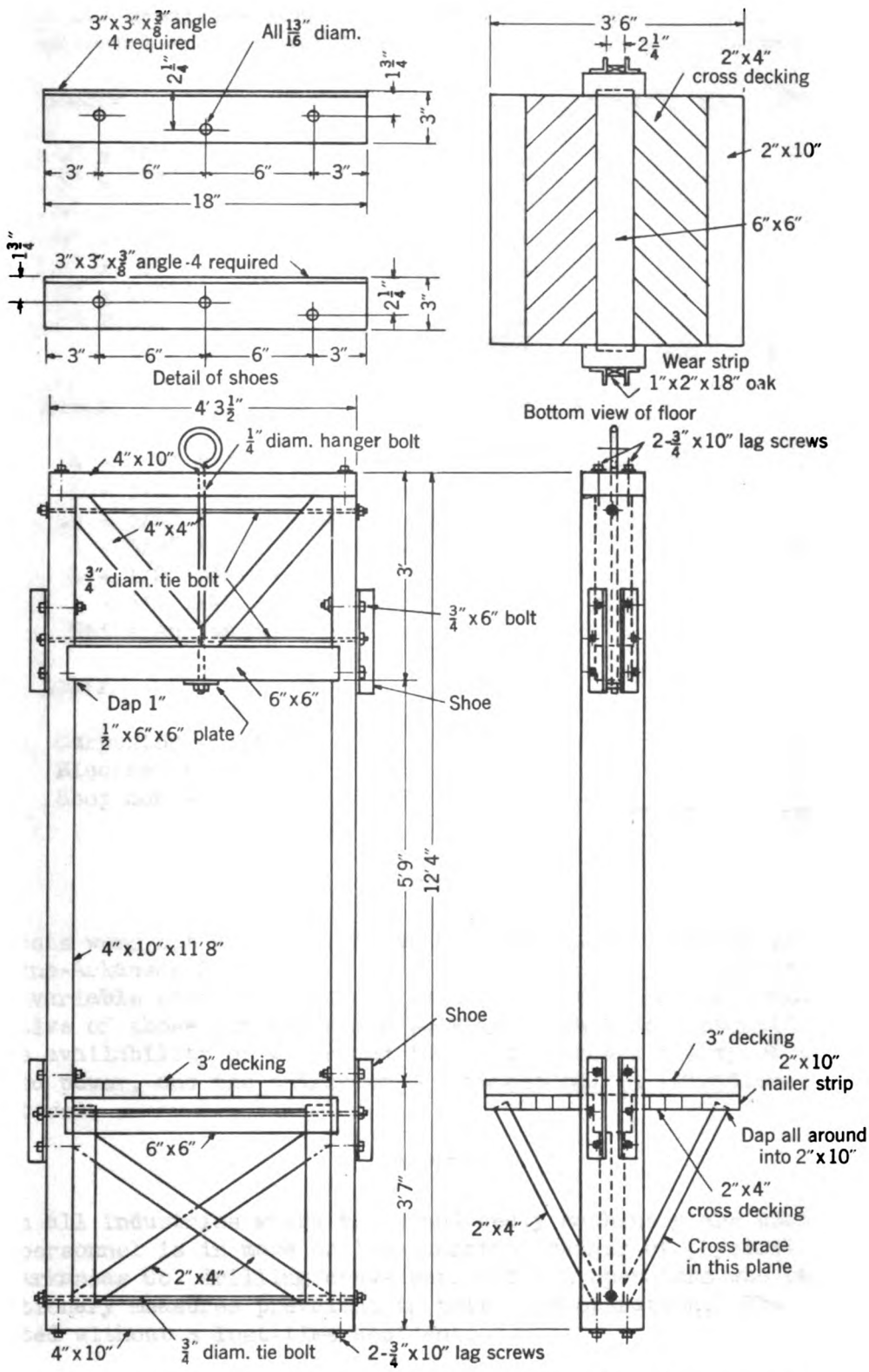

FIGURE 7.- Detail of guide aligning cage.

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Detailed specifications of the cage are shown in figure 7, and the bill of material and estimated costs necessary for its construction follows:

Timber	Bd. ft.	Weight, lb.	Cost
4" x 10"	106		
6" x 6"	23		
4" x 4"	7		
2" x 4"	51		
2" x 6"	7		
2" x 10"	12		
3" Plank	44		
	250	920	$ 7.50
Steel			
4 - 3' x 3" x 3/8" angle		65	2.68
8 - 3/4" x 10" lag screws		10	.48
16 - 3/4" x 6" bolts		12	.64
6 - 3/4" x 4'7" tie bolts		41	1.64
1 - 1/2" plates 6" x 6"		5	.20
1 - 5'1-1/4" round rod		21	.85
Nails and washers		20	1.40
Labor			
Carpenter - 3 days			22.80
Blacksmith - 1 hour			1.05
Shop men - 3 hours			3.15
	Total	1,090	42.39

COSTS

Costs were not available from the contractor. Kenneth Gilbert, of the Layne-Arkansas Co., stated that, in his opinion, costs for such work are so variable that any figures given for this operation would not be indicative of those for any other location. Factors controlling the cost are the availability of water and labor, the accessibility of the shaft site and power, and the character of the geological formations to be encountered.

SAFETY

In all industries where tools and heavy machinery are used the operating personnel is in more or less constant danger of physical injury. Layne-Arkansas Co. drilling crews were skilled operators who observed the precautionary measures prevalent in this type operation. The contract was completed without a lost-time accident.

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ADOPTION OF METHOD IN OTHER MINING AREAS

The Layne-Arkansas Co. has never undertaken shaft-sinking operations by the method described either in any other mining district or in solid, rock formations. However, another associate company of Layne & Bowler, Inc. - the Layne-Northwest Co., Milwaukee, Wis. - has successfully used the rotary-drill method to sink shafts in rock formations.

CONCLUSIONS

Shafts in circular cross section, lined with a steel casing that is surrounded by a cement seal, have structural advantages superior to those of shafts supported by timbers and sheeting. Where formations are unconsolidated and water-filled, shaft-sinking by means of the rotary drill is undoubtedly a practical, economical, safe method.

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